PATENT COOPERATION TREATY

10/030342

From the INTERNATIONAL BUREAU

PCT

NOTIFICATION OF THE RECORDING OF A CHANGE

(PCT Rule 92bis.1 and Administrative Instructions, Section 422)

To:

WATERMARK PATENT & TRADEMARK ATTORNEYS
290 Burwood Road
Hawthorn, VIC 3122
AUSTRALIE

Date of mailing (day/month/year)
15 February 2002 (15.02.02)

Applicant's or agent's file reference
P17420PCAU

IMPORTANT NOTIFICATION

International application No.
PCT/AU00/00796

International filing date (day/month/year)
30 June 2000 (30.06.00)

1. The following indications appeared on record concerning:

[X] the applicant [ ] the inventor [ ] the agent [ ] the common representative

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2. The International Bureau hereby notifies the applicant that the following change has been recorded concerning:

[X] the person [X] the name [X] the address [X] the nationality [X] the residence

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3. Further observations, if necessary:
Assignment

4. A copy of this notification has been sent to:

[X] the receiving Office
[ ] the International Searching Authority
[ ] the International Preliminary Examining Authority
[ ] the designated Offices concerned
[X] the elected Offices concerned
[ ] other:

The International Bureau of WIPO
34, chemin des Colombettes
1211 Geneva 20, Switzerland
Facsimile No.: (41-22) 740.14.35

Authorized officer
Marie-Thérèse Priser
Telephone No.: (41-22) 338.83.38

PATENT COOPERATION TREATY

From the INTERNATIONAL BUREAU

PCT

NOTIFICATION OF ELECTION

(PCT Rule 61.2)

To:

Commissioner
US Department of Commerce
United States Patent and Trademark Office, PCT
2011 South Clark Place Room CP2/5C24
Arlington, VA 22202
ETATS-UNIS D'AMERIQUE

in its capacity as elected Office

Date of mailing (day/month/year) 16 February 2001 (16.02.01)	
International application No. PCT/AU00/00796	**Applicant's or agent's file reference** P17420PCAU
International filing date (day/month/year) 30 June 2000 (30.06.00)	**Priority date** (day/month/year) 30 June 1999 (30.06.99)
Applicant O'BRIEN, Fergus et al	

1. The designated Office is hereby notified of its election made:

[X] in the demand filed with the International Preliminary Examining Authority on:

12 December 2000 (12.12.00)

[ ] in a notice effecting later election filed with the International Bureau on:

2. The election [X] was

[ ] was not

made before the expiration of 19 months from the priority date or, where Rule 32 applies, within the time limit under Rule 32.2(b).

The International Bureau of WIPO **34, chemin des Colombettes** **1211 Geneva 20, Switzerland**	Authorized officer R. E. Stoffel
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Form PCT/IB/331 (July 1992)

AU0000796

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PATENT COOPERATION TREATY

PCT

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

(PCT Article 36 and Rule 70)

Applicant's or agent's file reference P17420PCAU RCS/SMM/TJ	**FOR FURTHER ACTION**	See Notification of Transmittal of International Preliminary Examination Report (Form PCT/IPEA/416).
International Application No. **PCT/AU00/00796**	International Filing Date *(day/month/year)* 30 June 2000	Priority Date *(day/month/year)* 30 June 1999

International Patent Classification (IPC) or national classification and IPC

Int. Cl. [7] G06F 15/16, H04L 12/56

Applicant

TELEFONAKTIEBOLAG L M ERICSSON et al

1. This international preliminary examination report has been prepared by this International Preliminary Examining Authority and is transmitted to the applicant according to Article 36.

2. This REPORT consists of a total of 3 sheets, including this cover sheet.

   [X] This report is also accompanied by ANNEXES, i.e., sheets of the description, claims and/or drawings which have been amended and are the basis for this report and/or sheets containing rectifications made before this Authority (see Rule 70.16 and Section 607 of the Administrative Instructions under the PCT).

   These annexes consist of a total of **1** sheet(s).

3. This report contains indications relating to the following items:

I	[X]	Basis of the report
II	[ ]	Priority
III	[ ]	Non-establishment of opinion with regard to novelty, inventive step and industrial applicability
IV	[ ]	Lack of unity of invention
V	[X]	Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement
VI	[ ]	Certain documents cited
VII	[ ]	Certain defects in the international application
VIII	[ ]	Certain observations on the international application

Date of submission of the demand	Date of completion of the report
12 December 2000	30 May 2001
Name and mailing address of the IPEA/AU AUSTRALIAN PATENT OFFICE PO BOX 200, WODEN ACT 2606, AUSTRALIA E-mail address: pct@ipaustralia.gov.au Facsimile No. (02) 6285 3929	Authorized Officer **SEAN APPLEGATE** Telephone No. (02) 6283 2207

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

International application No.
PCT/AU00/00796

I. Basis of the report

1. With regard to the **elements** of the international application:*

☐ the international application as originally filed.

☒ the description, pages **1-11**, as originally filed,
pages , filed with the demand,
pages , received on with the letter of

☒ the claims, pages , as originally filed,
pages , as amended (together with any statement) under Article 19,
pages , filed with the demand,
pages **12**, received on **15 May 2001** with the letter of **15 May 2001**

☒ the drawings, pages **1/5-5/5**, as originally filed,
pages , filed with the demand,
pages , received on with the letter of

☐ the sequence listing part of the description:
pages , as originally filed
pages , filed with the demand
pages , received on with the letter of

2. With regard to the **language**, all the elements marked above were available or furnished to this Authority in the language in which the international application was filed, unless otherwise indicated under this item.
These elements were available or furnished to this Authority in the following language which is:

☐ the language of a translation furnished for the purposes of international search (under Rule 23.1(b)).

☐ the language of publication of the international application (under Rule 48.3(b)).

☐ the language of the translation furnished for the purposes of international preliminary examination (under Rules 55.2 and/or 55.3).

3. With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, was on the basis of the sequence listing:

☐ contained in the international application in written form.

☐ filed together with the international application in computer readable form.

☐ furnished subsequently to this Authority in written form.

☐ furnished subsequently to this Authority in computer readable form.

☐ The statement that the subsequently furnished written sequence listing does not go beyond the disclosure in the international application as filed has been furnished.

☐ The statement that the information recorded in computer readable form is identical to the written sequence listing has been furnished

4. ☐ The amendments have resulted in the cancellation of:

☐ the description, pages

☐ the claims, Nos.

☐ the drawings, sheets/fig.

5. ☐ This report has been established as if (some of) the amendments had not been made, since they have been considered to go beyond the disclosure as filed, as indicated in the Supplemental Box (Rule 70.2(c)).**

* *Replacement sheets which have been furnished to the receiving Office in response to an invitation under Article 14 are referred to in this report as "originally filed" and are not annexed to this report since they do not contain amendments (Rules 70.16 and 70.17).*

** *Any replacement sheet containing such amendments must be referred to under item 1 and annexed to this report*

V. Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

1. Statement

Novelty (N)	Claims	**1-7**	**YES**
	Claims	**None**	**NO**
Inventive step (IS)	Claims	**1-7**	**YES**
	Claims	**None**	**NO**
Industrial applicability (IA)	Claims	**1-7**	**YES**
	Claims	**None**	**NO**

2. Citations and explanations (Rule 70.7)

(a) US 5602839 (Anaapareddy et al.) 11 February 1997.

(b) EP 637152 (IBM) 1 February 1995.

(c) EP 404339 (DEC) 27 December 1990.

The invention defined in claims 1-7 satisfies the requirements of novelty and inventive step when compared with documents (a) to (c) above because none of these documents when considered either alone or in obvious combination clearly disclose a computer system based on a "small world" principle in which nodes are clustered in interconnected neighbourhoods and there is a relatively small number of cross links between nodes of different neighbourhoods.

THE CLAIMS DEFINING THE INVENTION ARE AS FOLLOWS:

1. A telecommunications/computer system having a plurality of nodes, such that the plurality of nodes are clustered in a plurality of interconnected neighborhoods, the system characterised in that a relatively small number of cross-links are provided between nodes of different neighborhoods.

2. The system of claim 2 wherein the relatively small number of connections are random links.

3. The system of claim 2 or 3 wherein the neighborhoods are fully interconnected.

4. The system of claim 1 wherein the mean connectivity between nodes of different neighborhoods is in the range of about 1.5 to 2.0.

5. The system of claim 1 wherein the mean connectivity between nodes of different neighborhoods is about 1.6.

6. A large scale computer system including a multiplicity of nodes, each node having a plurality of interconnected processors, said nodes being arranged in a network with neighboring sets of nodes of the network forming neighborhoods of fully interconnected nodes, wherein random links are provided between nodes of different neighborhoods in the network whereby each processor of the system can communicate effectively with other processors regardless of their location in the network without full connectivity in the network.

7. A scalable computer system formed using a small world principle.

INTERNATIONAL SEARCH REPORT

International application No.
PCT/AU00/00796

A. CLASSIFICATION OF SUBJECT MATTER

Int. Cl. [7]: G06F 15/16, H04L 12/56

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
G06F 15/16, 15/163, 15/173, H04L 12/56

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
AU: IPC as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
Derwent WPAT, USPTO
keywords: interconnection, links, routing, random

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X A	US 5602839 A (Annapareddy et al.) 11 February 1997 See whole document	1, 7 2 - 6
X A	EP 637152 A (International Business Machines Corporation) 1 February 1995 See whole document	1, 7 2 - 6
X A	EP 404339 A (Digital Equipment Corporation) 27 December 1990	1, 7 2 - 6

☐ Further documents are listed in the continuation of Box C ☒ See patent family annex

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
11 August 2000	29 August 2000

Name and mailing address of the ISA/AU	Authorized officer
AUSTRALIAN PATENT OFFICE PO BOX 200, WODEN ACT 2606, AUSTRALIA E-mail address: pct@ipaustralia.gov.au Facsimile No. (02) 6285 3929	CATHERINE REES Telephone No : (02) 6283 2555

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/AU00/00796

This Annex lists the known "A" publication level patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent Document Cited in Search Report		Patent Family Member					
US	5602839	CN	1157512	EP	773652	JP	9153892
EP	637152	CA	2123449	JP	7066835	US	5491690
EP	404339	CA	2011399	JP	3032253	US	5179558

END OF ANNEX

#4

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

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PCT

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(30) Priority Data:
PQ 1286 30 June 1999 (30.06.1999) AU

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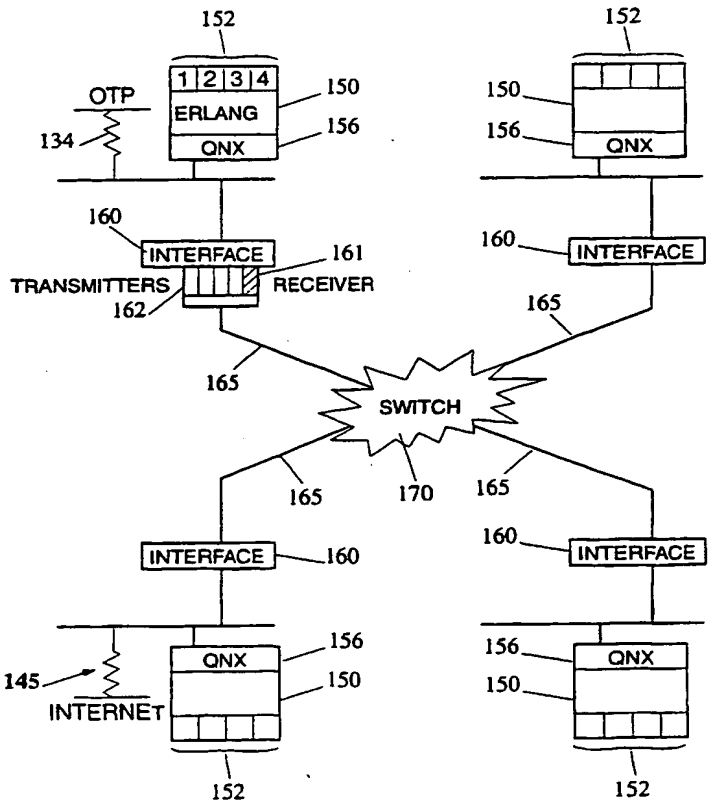
(81) Designated States *(national)*: AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CR, CU, CZ, DE, DK, DM, DZ, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, US, UZ, VN, YU, ZA, ZW.

(84) Designated States *(regional)*: ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE,

[Continued on next page]

(54) Title: A SCALABLE COMPUTER SYSTEM



(57) Abstract: The present invention utilizes a "small-world" network architecture, in which a relatively small number of random cross-links of nodes or vertices in a network can result in small characteristic path lengths, for the transfer of messages between modes or vertices in a telecommunications/computer network regardless of their location. The "small world" principle is usually considered to apply to many biological and social networks, as these systems generally exhibit properties that are not completely regular or completely random but somewhere in between. The present invention applies this small world principle to telecommunications/computer networks.

WO 01/02972 A1

IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

Published:
— *With international search report.*

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

A SCALABLE COMPUTER SYSTEM

FIELD OF THE INVENTION

This invention relates to computer systems and more particularly, but not exclusively, to a computer system which is required to have a large number of computer processors for use in large scale system applications. The present invention has application to scalable telecommunications and intelligent networks.

BACKGROUND ART

Recent developments in telecommunications and intelligent networks, primarily involving the field of photonics, are resulting in a rapid expansion of bandwidths available for communication. The available bandwidth is currently growing at a rate involving, roughly, a factor of two every two years, and it is anticipated that communication bandwidths may increase by at least three orders of magnitude over the next ten years.

In order to match this rapid bandwidth growth in the level of telecommunications, equivalent computing power is required. It is therefore desirable to design a computer based system architecture that is massively scalable. The scalability is essentially driven by the number of independent users, as in mobile phone devices, rather than the complexity or size of an individual application.

Hitherto, there has been no known solution to the problem of designing a massively scalable architecture for the intelligent network (IN) domain.

The Internet is a large computer system, but it is a hierarchical system and hence does not address the issue of massive scalability.

Other computer system architectures that are known are only scalable in many orders of magnitude less than what will be required in the near future in telecommunications and intelligent networks.

For example, the computer system of Figure 1 is based on an Erlang/Open Telecom Platform (OTP) running on a single node. The computer system 10 includes hardware 12, an operating system 14, a display 16 and a keyboard 18 and a suite of programs 20 which include application programs 22 (eg. in programming languages, Erlang and C), sourced programs 24, run-time programs

26, a library 28, and a database 30. The system may be linked to an external database 32 if required.

The single node provides reasonable system development facilities, including an Erlang real time environment, or interpretive environment. However, this is achieved at the expense of potential performance owing to the interpreter/operating system layers.

The single node computer system of Figure 1 may be linked to other similar nodes by an asynchronous transfer node (ATM) switch, such as the AXD-301 switch with satisfactory performance. However, this switch has a scalability of 1:30, which is orders of magnitude less than that which is required for ultra high communication bandwidths.

Referring to Figure 2, there is shown a split node computer system in which an OTP node 34 is split into two closely couple nodes: a COTS (commodity of the shelf) system 40 and a multi-processor (MP) Erlang Engine 50. The COTS system is essentially the base system and may comprise of a UNIX operating platform 41, application programs (eg. in C, C++, Java and Erlang) 42, a disc drive 43, graphics 44, an Internet modem 45, an Internet interface (TCP/IP) 46 and an input/output interface (I/O) 47 for communicating with the Erlang Engine 50.

The Erlang Engine 50 is a shared memory MP system running software 52 and 54 in Erlang on top of an optimized message passing kernel (56) such as QNX. The Erlang Engine 50 also has an I/O interface 58 for communicating with the COTS system 40. One processor of the MP set can be devoted to monitoring software, the remainder to functional processing.

The split node OTP system 34 of Figure 2 may form part of a network that includes a plurality of regional processors (RP) 61 and support processors (SP) 62 for operators. The regional and support processors 61, 62 are connected to central processors CP A 63 and CP B 64 and to each other by a high speed RP bus 65. The MP Erlang Engine 50 includes a high speed interface 59 for communicating with the central processors CP A 63 and CP B 64.

The split node OTP system 34 can be linked to other computer systems by a switch 70 such as an AXE-10. For this purpose an AXE programming system (APS) 72 may be provided. In a telecommunications application, the interface

shown to the AXE-10 may be implemented as a high speed Ethernet, primarily due to the availability of the Ethernet PLEX (Programming Language for Exchanges) blocks existing on AXE-10. The Erlang to PLEX interface has been demonstrated in two modes, firstly with the AXE-10 controlling the links, as in a call forwarding application. The second mode is with OTP in control, with an application such as remote changes to AXE-10 tariff tables.

The scalability limit of the Erlang Engine is a maximum of eight processors, given that it is a shared memory environment. The eight processors, together with a demonstrated 5 x speed up from the move to compiled code, plus 2 x moving from Unix to QNX gives a scale-up of 80 from the base system.

Therefore it is apparent that both of these known systems have limitations in terms of their scalability and could not be considered massively scalable.

It is therefore desirable to provide a massively scalable computer system including a large number of processors in which each processor can communicate effectively with other processors without regard to their locations.

SUMMARY OF THE INVENTION

According to one aspect the present invention provides a telecommunications system having a plurality of nodes, such that the plurality of nodes are clustered in a plurality of interconnected neighborhoods, the system characterised in that a relatively small number of cross-links are provided between nodes of different neighborhoods.

According to another aspect, the present invention provides a large scale computer system including a multiplicity of nodes, each node having a plurality of interconnected processors, said nodes being arranged in a network with neighbouring sets of nodes of the network forming neighbourhoods of fully interconnected nodes, wherein random links are provided between nodes of different neighbourhoods in the network whereby each processor of the system can communicate effectively with other processors regardless of their location in the network without full connectivity in the network.

In essence, the present invention has come about through the realisation that problems associated with telecommunication and intelligent network

scalability and/or computer architecture design, can be addressed by applying the "small world" principle.

The "small world" concept was derived from the "six degrees of separation" principle. Six degrees of separation is a theory that a person may reach anyone in the world through at the most six personal contacts. This theory was explored through an Internet site based upon the actor Kevin Bacon. This site was created out of curiosity, but was a very useful sociological experiment for illustrating the six degrees of separation principle. The site however, gave no hint as to any underlying structure of the people involved in the interconnections.

The key to the underlying structure may be derived from studies into epidemics. For example diseases, such as the Black Death spread with great rapidity from one part of the world to another: from the Middle East to Europe. In that situation, the epidemic mechanism was that of an area that already had the disease within a defined group, and a single vector, such as ship-borne rats travelling to another defined group.

By understanding the relationship between epidemics and the six degrees of separation principle, it is apparent that the underlying structure of the six degrees of separation principle was a set of richly connected groups with a small number of inter-group links. It is this combination of richly connected neighborhoods, with a small number of links between them that is termed a "small world" network.

In other words, the present invention utilizes a "small-world" network architecture, in which a relatively small number of random cross-links of nodes or vertices in a network can result in small characteristic path lengths, for the transfer of messages between nodes or vertices in a telecommunications/computer network regardless of their location.

BRIEF DESCRIPTION OF THE DRAWINGS

A preferred embodiment of the present invention will now be described, by way of example only, with reference to the accompanying drawings in which: -

Figure 1 is a diagram of a prior art single node computer system, which has limited scalability;

Figure 2 is a diagram of a prior art split node computer system;

Figure 3 is a diagram showing the difference between a "small world" network and regular ring and random networks;

Figure 4 is a graph showing variations in clustering and average path length with increasing randomness in a ring network.

Figure 5 is a diagram of a four-node computer system having four processors per node.

Figure 6 is a diagram of a small-world architecture for a computer system in accordance with the invention.

DETAILED DESCRIPTION

The "small world" principle is usually considered to apply to many biological and social networks, as these systems generally exhibit properties that are not completely regular or completely random but somewhere in between. For example, infectious diseases exhibit "small world" properties. In this regard, it has been shown that infectious diseases spread more easily in small world networks than regular lattices.

The present invention applies this small world principle to telecommunications/computer networks. A comparison of the performance of a small world telecommunications network, to that of regular and random telecommunications networks will now be provided. Examples of regular, small-world and random networks are shown in Figure 3.

In very large telecommunications networks with only local connections most vertices or nodes in the network are separated by many links. In regular lattice or ring structures with local connections between vertices or nodes, the characteristic or mean distance of the path length (L) between two vertices or nodes grows approximately linearly with the size of the network. On the other hand, in a network with only random connections between vertices or nodes, the characteristic path length (L) grows logarithmically with the number of vertices or nodes. A network with only random connections, however, is a poorly clustered environment, as a sparse number of random connections can result in some vertices or nodes not being inter-connected to other nodes at all.

A small world telecommunications network in accordance with the present invention is one in which vertices or nodes in local "neighborhoods" or "clusters"

are interconnected to each other, and a relatively small number of random links or connections are provided between nodes of different neighborhoods of the network.

In "Collective dynamics of "small-world networks" by Duncan J. Watts & Steven H. Strogatz, Nature, Vol. 393, pp. 440-442, a mathematical approach to defining structural properties of small-world networks was provided in terms of characteristic path length L(p) and clustering coefficient C(p). L(p) measures the typical separation between two vertices in a network (a global property) and C(p) measures the clustering or connections in a typical neighborhood (a local property), where p is a probability factor.

In a regular network having n nodes and k edges or links per nodes, p = 0, L (0) grows linearly with n, the number of nodes in the network, and C(0) depends on the specific geometry or 'wiring' of the network.

In a completely random network with only random connections, p = 1 and L-random grows logarithmically with n, whereas C-random $\simeq$ k/n « 1.

"Small-world" networks, on the other hand, have a broad interval of p over which L(p) is almost small as L random, yet C(p) is much greater than C-random. This is shown in the graph of Figure 4.

Watts and Strogatz thus demonstrated numerically that a few random global connections are sufficient to turn a regular network into a small-world network to reduce the path length of the number of links for effective communication between nodes or vertices drastically.

Hanspeter Herzel in his article entitled "How to Quantify Small-World Networks" (Fractals, Vol. 6, No. 4 (1998) 301-303) derived a formula for the mean connectivity k^{eff} of nodes in a small-world ring network. For a ring network with k edges of links per node, in which a fraction of p connections are re-wired randomly the formula was:

$$k^{eff} = k \cdot p$$

When $k^{eff} > 1$, the characteristic path length L(p) may be expressed as follows:

$$L(p) = \frac{\ln(n)}{\ln(k^{eff})} = \frac{\ln(n)}{\ln(k) + \ln(p)}$$

Such a logarithmic curve approximates the curve L(p)/L(0) in Figure 4.

In the present invention, the number of nodes in the network, the number of nodes in the neighborhood, the number of nodes per neighborhood and the number of cross-links in the network may each be varied for different applications, provided that the network functions as a small-world network with large clustering C(p) and small average path lengths L(p).

The cross-links in the small-world network of the present invention may be chosen completely at random. Alternatively, a pseudo-random selection process may be used to select the cross-links between neighborhoods to convert a regular network into a highly clustered small-world network with a relatively small average path length. In this regard, an acceptable result in terms of the number of hops per inter-process message, from a system process point-of-view, is under two.

In one preferred embodiment of the invention a mean connectivity falling substantially in the range from about 1.5 to about 2.0, and preferably about 1.6, may be achieved by appropriate choice of the number of nodes per neighborhood, the connectivity of each neighborhood and/or the number of cross-links relative to the total number of nodes in the network. By way of example, in a computer system having 50 neighborhoods of 10 nodes arranged in a ring network with about 50 cross-links between neighborhoods, each node is connected to 9 other nodes in its neighborhood (k = 9) and the probability factor p = 50 x 2/500. Thus

$$k^{eff} = 9 \times \frac{100}{500} = 1.8$$

The number of interconnected processors in each node of the computer system may also vary for different applications. With the development of photonics, it is envisaged that up to about 256 nodes, each containing up to eight processors per node may be fully connected together by optical fibres and a high speed switch to form a single neighborhood in a small-world network. With a large number of such neighborhoods in the small-world network connected by a relatively small number of cross-links, it is possible to achieve a massively

scalable computer system with a very large number of total processors in the system which are able to communicate with each other in an effective manner.

There will now be explained with reference to Figure 6, an example of how a "small-world" network architecture can be used to achieve a large scale computer system of about one million processors in which each processor of the system is able to communicate effectively with other processors in the system without requiring full connectivity.

Figure 6 shows a small-world telecommunications network in which there are 20 nodes arranged in a ring layout. The 20 nodes of the ring network can be considered to form five neighborhoods of nodes A, B, C, D and E in which there are four nodes (A_1 to A_4; B_1 to B_4; C_1 to C_4; D_1 to D_4; and E_1 to E_4) per neighborhood.

Each node eg A_2 is connected to adjacent nodes A_1, A_3 by an edge link EL and alternate nodes eg A_1, A_3; A_2, A_4; A_3, B_1 are connected to each other by a small loop link LL.

A network connected only in this manner would normally be termed a regular network in which messages from one node, eg A_1, must pass through a relatively large number of links to reach a node at the opposite side of the network, eg C_4.

A small-world network such as shown in Figure 6, differs from a regular network in that a relatively small number of random cross-links are provided between neighborhoods of nodes. In the example of Figure 6, there are three cross-links CL_1, CL_2 and CL_3. Cross-link CL_1 directly connects nodes A_2 and C_1 with each other; cross-link CL_2 directly connects nodes B_2 and E_3 with each other and cross-link CL_3 directly connects nodes D_1 and E_4 with each other. It will be apparent from Figure 6 that there is a marked increase in connectivity with only a relatively small number of cross-links between neighborhoods of nodes. For instance, a message to be sent from node A_1 to C_2 can pass along an edge link EL to node A_2, along cross-link CL_1 to C_1 and then along an edge link to C_2. This is a clear improvement over a regularly connected network, where the message would pass along four loop links to C_1 and an edge link EL to C_2. Also, a message from B_4 to E_2 can pass along a loop link to B_2, along cross-link CL_2 to E_4 and then along another loop link LL to E_2, rather than along five loop links.

It will be seen from Figure 6 that a small-world network is an architecture that can be used to link together a relatively large number of computer processors while retaining effective connectivity between the processors.

In a preferred embodiment of the invention, each neighborhood of Figure 6 corresponds to the four-node/four-process per node computer system shown in Figure 5. Referring to Figure 5, there is shown a system that demonstrates it is possible to link up several MP Erlang Engines of the type shown in Figure 2 through a high-speed blocking switch. Each node of the computer system of Figure 5 is an Erlang Engine 150 with four processors 152 running on a QNX kernel 156. Each Erlang Engine 150 may include a link to an OTP system 134 in similar manner to split node system of Figure 2 and may also have a local Internet connection 145.

The Erlang Engines 150 are connected to each other by optical interfaces 160, optical fibres 165 and a common high speed non-blocking optical switch 170. Each optical interface 160 may include at least one optical receiver 161 and one or more optical transmitters 162.

Currently available interface blocks 160 can handle 32 separate wavelengths: this is predicted to rise to 256 with further developments in photonics. This will permit up to 256 nodes (Erlang Engines) in a computer system such as that of Figure 5, as each node can be essentially addressed by an individual wavelength.

A key attribute of the system of Figure 5 is that the interface blocks can transmit one or more wavelengths, up to 256, with the same data simultaneously as a multicast facility. However, each node only receives on one wavelength: its address.

Since the system gives almost linear scaling on separable problems, 256 nodes can give a speed-up of 20,000 over the basic system.

It will be noted that the computer system of Figure 5 is a fully connected system in the sense that each Erlang Engine 150 has its own dedicated optical fibre link 165 to the central switch 170.

Applying the system of Figure 5 to the small world network of Figure 6, it is apparent that even where each neighborhood is a four node/four processors per

node system, a total of eighty processors can be effectively linked together by the 20 node network of Figure 6 with only 3 cross-links.

It is however, to be appreciated that the small-world network of Figure 6 is, however, only a relatively small-scale example of such a network. Within the scope of the present invention it is contemplated that at least 500 neighborhoods of nodes each having up to 256 fully connected Erlang Engines per node with 8 processors per Erlang Engine could be linked together in a small-world network to achieve a total system of over one million processors, with the small-world network architecture providing effective connectivity between the nodes with only a relatively small number of cross-links, say 50, between the neighborhoods. For example, the total number of individual Erlang processors running on such a system will be of the order of 256,000,000 assuming 2000 active processors per Erlang Engine node. This gives around 25.6 million lines of code, which is of the order of magnitude already envisaged for large software systems project.

It is envisaged that a massively scalable computer system in accordance with the invention has widespread applications. In the telecommunications field, the scalability could cover applications such as mobile telephone services for stockbroking, betting and other services. The invention may also be applied to Internet proxy servers in order to accommodate an escalating number of users.

More particularly in relation to the mobile telecommunications field, the present invention may be used as a "personal information manager in the sky" whereby it coordinates communications with handheld communications devices, such as Personal Digital Assistants (PDAs).

A further application is microbank applications, whereby the present invention may be used by financial institutions in order to allow them to economically handle extremely large numbers of transactions, particularly relating to very small amounts.

It will be appreciated that various modifications and alterations may be made to the present invention as described above without departing from the scope and spirit of the present invention. For instance, as mentioned above, the size of the network, the neighborhoods in the network, the number of nodes per

neighborhood, the number of cross-links between neighborhoods and the number of processors per node may be varied for different applications.

THE CLAIMS DEFINING THE INVENTION ARE AS FOLLOWS:

1. A telecommunications/computer system having a plurality of nodes, such that the plurality of nodes are clustered in a plurality of interconnected neighborhoods, the system characterised in that a relatively small number of cross-links are provided between nodes of different neighborhoods.

2. The system of claim 2 wherein the relatively small number of connections are random links.

3. The system of claim 2 or 3 wherein the neighborhoods are fully interconnected.

4. The system of claim 1 wherein the mean connectivity between nodes of different neighborhoods is in the range of about 1.5 to 2.0.

5. The system of claim 1 wherein the mean connectivity between nodes of different neighborhoods is about 1.6.

6. A large scale computer system including a multiplicity of nodes, each node having a plurality of interconnected processors, said nodes being arranged in a network with neighboring sets of nodes of the network forming neighborhoods of fully interconnected nodes, wherein random links are provided between nodes of different neighborhoods in the network whereby each processor of the system can communicate effectively with other processors regardless of their location in the network without full connectivity in the network.

7. A scalable computer system formed using a small world principle.

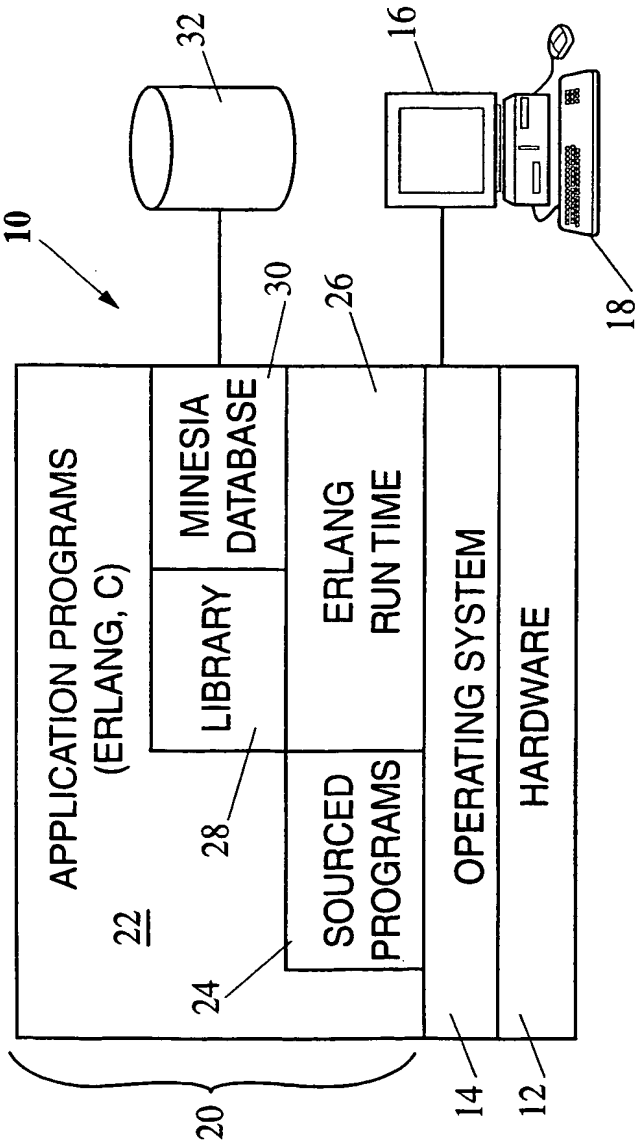


Fig 1.
(Prior Art)

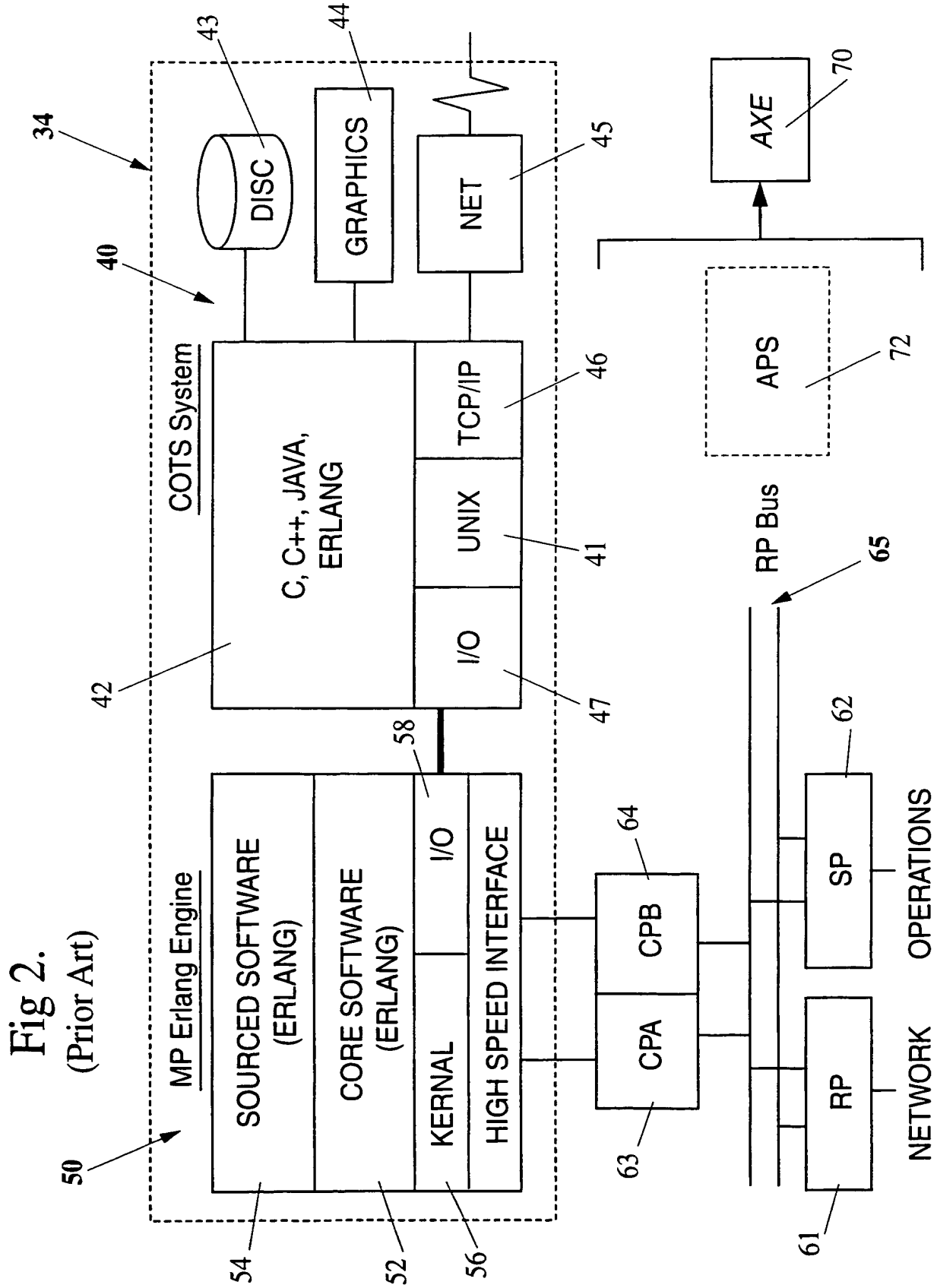


Fig 2.
(Prior Art)

Fig 3.

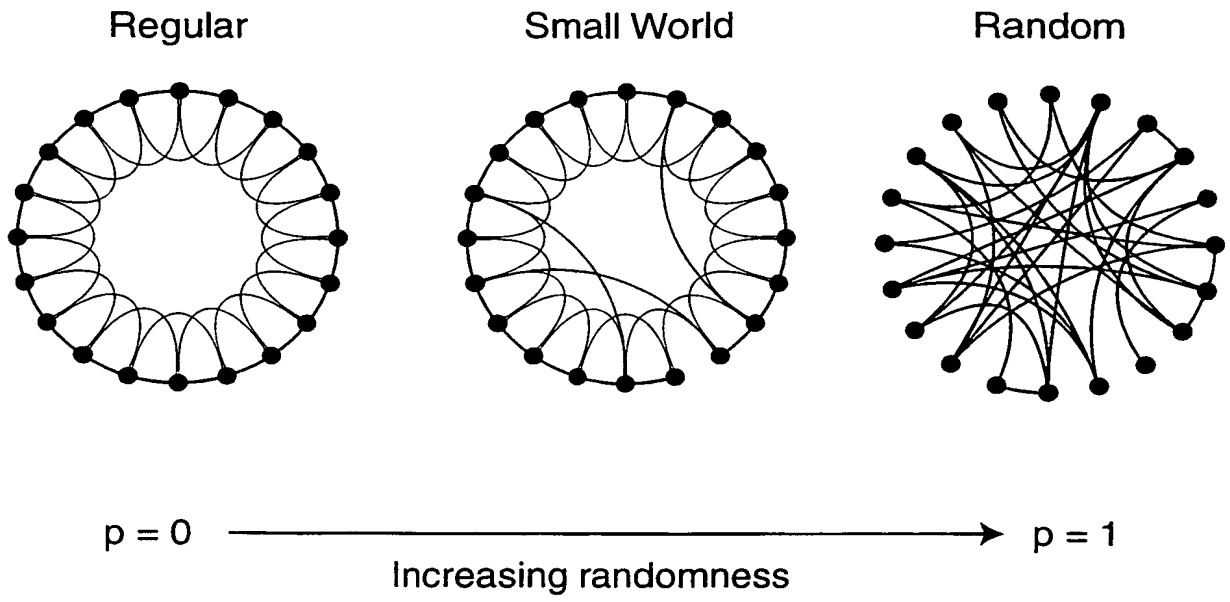

Regular
Small World
Random
p = 0
p = 1
Increasing randomness

Fig 4.

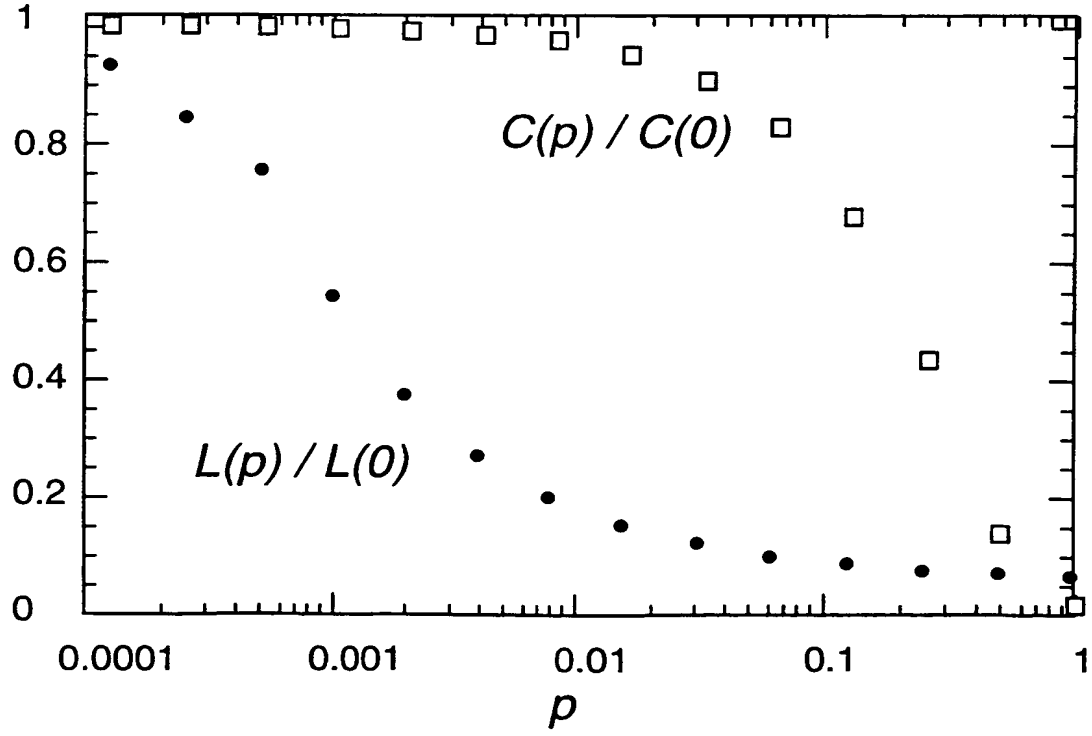

1
0.8
0.6
0.4
0.2
0
C(p) / C(0)
L(p) / L(0)
0.0001
0.001
0.01
0.1
1
p

Fig 5.

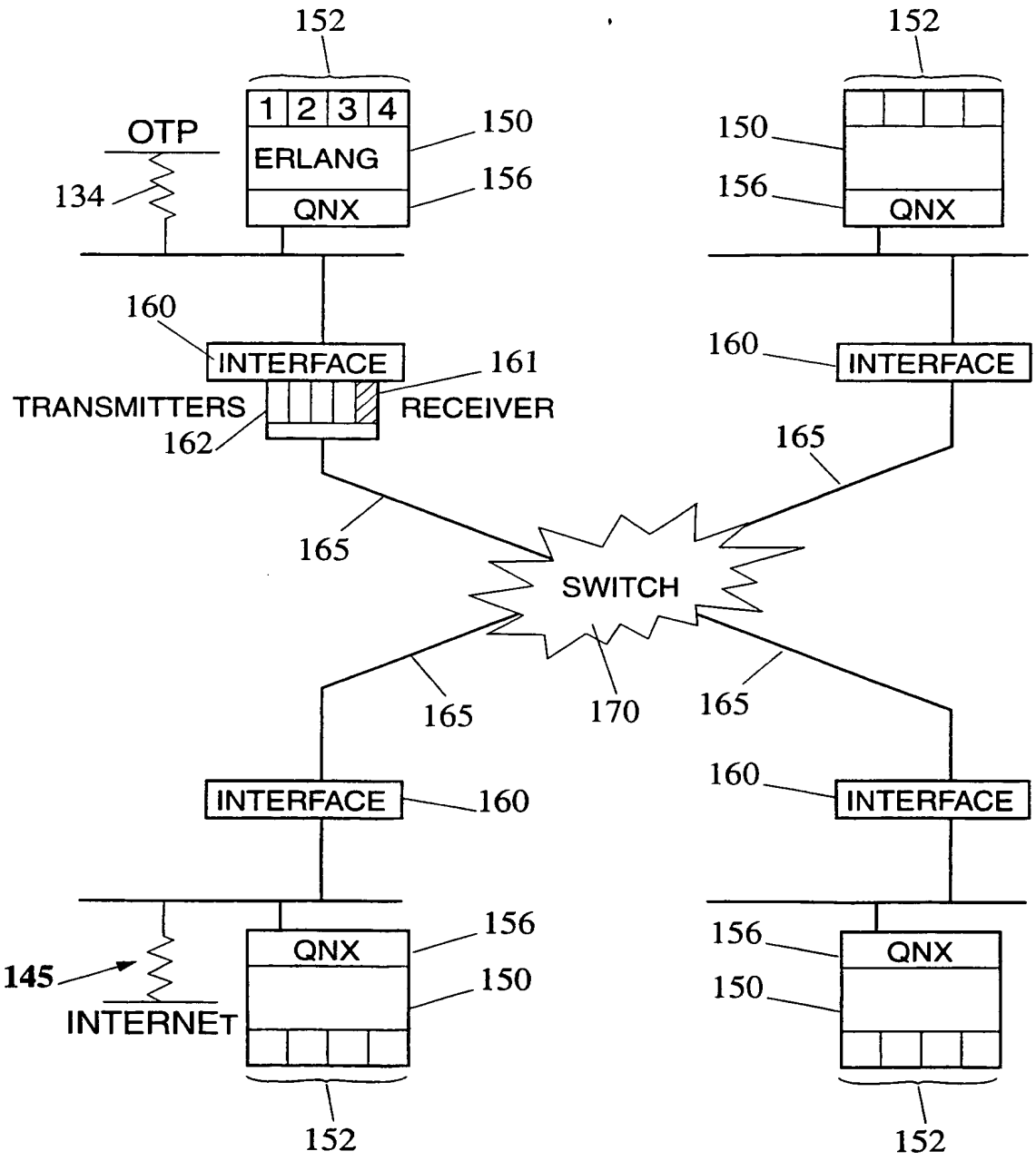
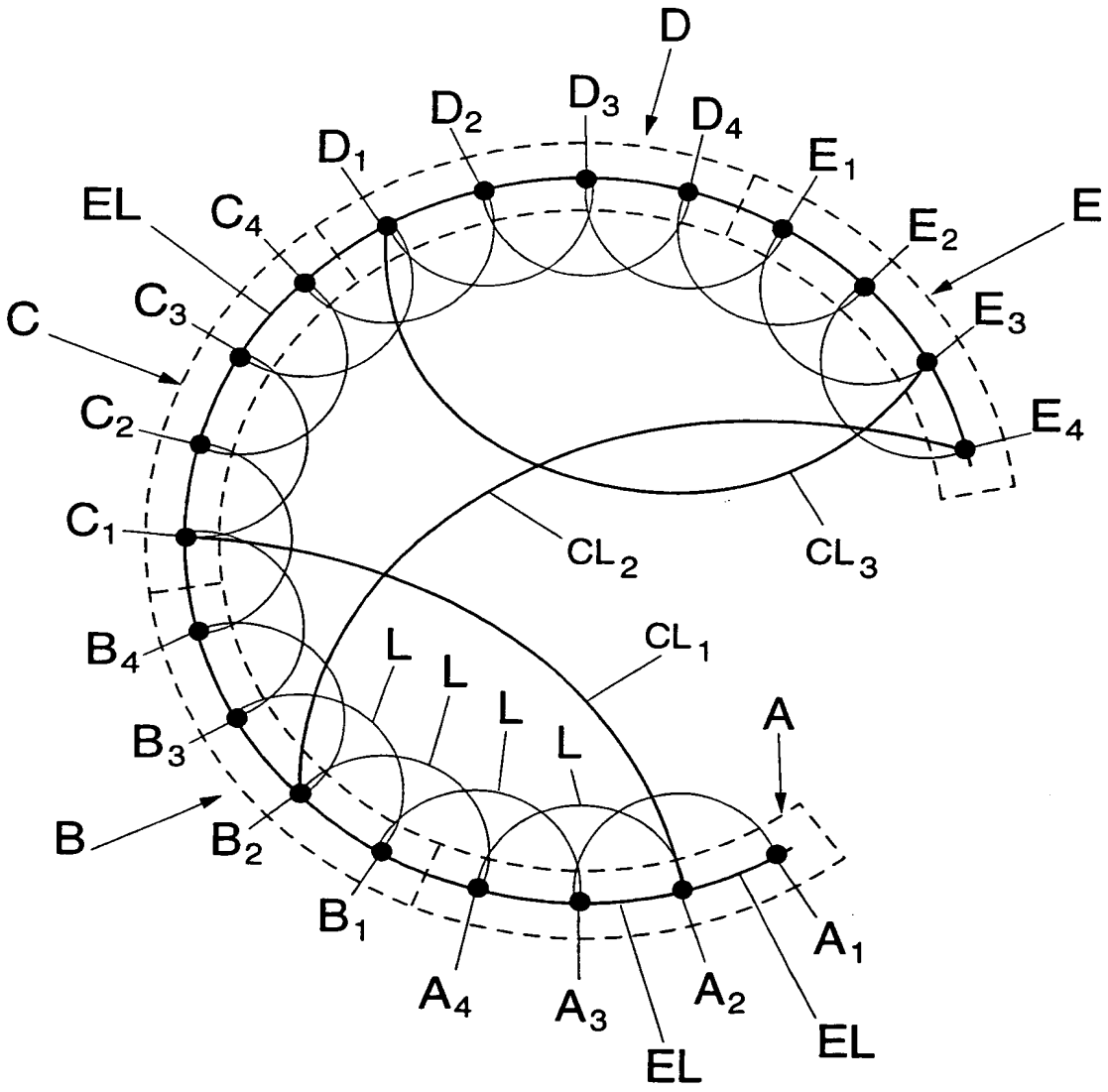

152
1 2 3 4
OTP
ERLANG
QNX
150
156
134
160
INTERFACE
161
TRANSMITTERS
RECEIVER
162
165
SWITCH
170
145
INTERNET

Fig 6.


D
D1
D2
D3
D4
E1
E2
E
E3
E4
EL
C4
C3
C
C2
C1
CL2
CL3
CL1
L
L
L
L
A
B4
B3
B
B2
B1
A4
A3
A2
A1
EL
EL

INTERNATIONAL SEARCH REPORT

International application No.
PCT/AU00/00796

A. CLASSIFICATION OF SUBJECT MATTER

Int. Cl. [7]: G06F 15/16, H04L 12/56

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
G06F 15/16, 15/163, 15/173, H04L 12/56

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
AU: IPC as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
Derwent WPAT, USPTO
keywords: interconnection, links, routing, random

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
	US 5602839 A (Annapareddy et al.) 11 February 1997	
X	See whole document	1, 7
A		2 - 6
	EP 637152 A (International Business Machines Corporation) 1 February	
X	1995	1, 7
A	See whole document	2 - 6
	EP 404339 A (Digital Equipment Corporation) 27 December 1990	
X		1, 7
A		2 - 6

☐ Further documents are listed in the continuation of Box C ☒ See patent family annex

* Special categories of cited documents:

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"E" earlier application or patent but published on or after the international filing date

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
11 August 2000	29 August 2000
Name and mailing address of the ISA/AU	Authorized officer
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INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/AU00/00796

This Annex lists the known "A" publication level patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

Patent Document Cited in Search Report		Patent Family Member					
US	5602839	CN	1157512	EP	773652	JP	9153892
EP	637152	CA	2123449	JP	7066835	US	5491690
EP	404339	CA	2011399	JP	3032253	US	5179558

END OF ANNEX